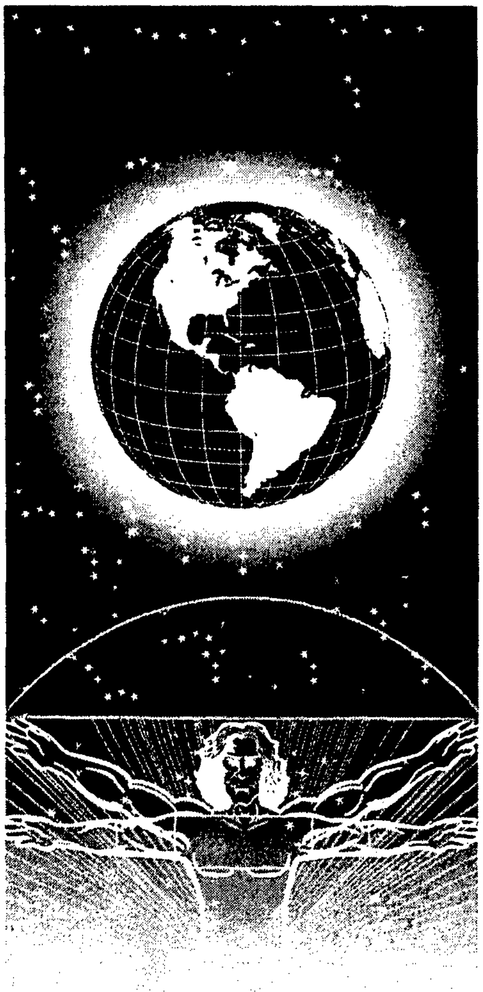
IOH-SD-BR-SR-2006-0008



UNITED STATES AIR FORCE
AFIOH

Technical Basis Document for the GR-460, Contamination Monitoring System

Jerry R. Hensley

December 2006

20070402130

Air Force Institute for Operational Health
Surveillance Directorate
Radiation Surveillance Division
2513 Kennedy Circle
Brooks City-Base TX 78235-5116

Distribution Statement A: Approved for public release; distribution unlimited.

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The mention of trade names or commercial products in this publication is for illustration purposes and does not constitute endorsement or recommendation for use by the United States Air Force.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

Government agencies and their contractors registered with Defense Technical Information Center (DTIC) should direct requests for copies to: Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Ft. Belvoir, VA 22060-6218.

Non-Government agencies may purchase copies of this report from: National Technical Information Services (NTIS), 5285 Port Royal Road, Springfield, VA 22161-2103.

//signed//

JERRY R. HENSLEY, DAF, CHP
Senior Health Physicist

//signed//

SCOTT M. NICHELSON, Lt Col, USAF, BSC, CHP
Chief, Radiation Surveillance Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	
2. REPORT DATE	1 December 2006
3. REPORT TYPE AND DATES COVERED	Final
4. TITLE AND SUBTITLE	**Technical Basis Document for the GR-460, Contamination Monitoring System**
5. FUNDING NUMBERS	
6. AUTHOR(S)	Jerry R. Hensley
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	Air Force Institute for Operational Health Surveillance Directorate Radiation Surveillance Division 2513 Kennedy Circle Brooks City-Base TX 78235-5116
8. PERFORMING ORGANIZATION REPORT NUMBER	IOH-SD-BR-SR-2006-0008
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	
10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT	Approved for public release; distribution unlimited.
12b. DISTRIBUTION CODE	A

13. ABSTRACT (Maximum 200 words)

The Air Force Institute for Operational Health is directed to support environmental remediation activities when radioactive materials are involved and has an emergency response element to respond to emergencies involving missing or dispersed radioactive materials. The Contamination Monitoring System (CMS) was designed to locate, identify, estimate activity, and reject natural background radiation with associated location (global positioning satellite system). The system collects the GPS coordinates via a Trimble GPS and associates the position with the spectral information collected by the 512 channel multi-channel analyzer (SAIC/Exploranium GR-460). The data is easily retrieved using the software supplied by the manufacturer. If a specific data point is located, the spectral information related to that position can be easily retrieved and viewed using various gamma analysis programs to determine if the material is the radionuclide of concern or naturally occurring background radiation.

14. SUBJECT TERMS	environmental radiation radiation measurement contamination monitoring system CMS radiation accident emergency response
15. NUMBER OF PAGES	28
16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT	Unclassified
18. SECURITY CLASSIFICATION OF THIS PAGE	Unclassified
19. SECURITY CLASSIFICATION OF ABSTRACT	Unclassified
20. LIMITATION OF ABSTRACT	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev.2-89)
Prescribed by ANSI Std. Z39-18

(This Page Intentionally Left Blank)

Table of Contents

List of Tables

List of Figures

Acknowledgements

This document would not be possible without the assistance of Maj David Pugh, Lt James Fyffe, TSgt Ty Richards, SSgt Cory Bahl, and SSgt Adam Lloyd for assisting in formulating a strategy to map the detector response to various radionuclides, run calculations, and making measurements using the various radionuclides and distances referenced in this document.

Special thanks to Mr. Thane Hendricks of the Department of Energy's Remote Sensing Laboratory for assistance in modifying a commercial-off-the-shelf system for monitoring surface and soil contamination and his patience for assisting in creating algorithms for identifying and quantifying various radionuclides for this system.

TECHNICAL BASIS DOCUMENT FOR THE GR-460, CONTAMINATION MONITORING SYSTEM

INTRODUCTION

This document will describe the operation and use of the SAIC/Exploranium GR-460 Contamination Monitoring System (CMS). The CMS is used to perform radiological surface and matrix contamination surveys, specifically radionuclides that emit gamma or x-ray radiation during their decay process. This document will also address instrument gamma energy calibration and detector efficiency.

As with any portable field radiological detection instrumentation, the detection limits addressed in this document are specific to the dimensions and conditions referenced. Since actual field conditions are not likely to be exactly per the model, the detection limits should only be used as a guide. Actual in situ measurements or samples should be obtained and analyzed for more accurate measurements. System minimum detectable activities should be calculated based on site-specific backgrounds and applicable standard deviation (σ) or minimum detectable activity calculations.

DESCRIPTION

The CMS consists of the GR-460 console, two 10 centimeter (cm) by 10 cm by 40 cm sodium iodide (NaI) detectors, a Trimble Ag 132 global positioning system (GPS), a trailer modified to carry detectors, and a laptop computer (optional). The detectors are oriented such that they are parallel to each other and oriented with the long axis in the direction of travel. The bottom of the detector case is 25.7 cm above the ground and the distance between the detectors is 29 cm. The distance between detectors and height above the surface was optimized for the detection of Am-241. The system is a total system in that it automatically records the operator's location to within 1 meter (requires OmniStar subscription service) and records the associated spectral data from each detector every second to a PCMCIA card inside the GR-460 console. Figure 1, CMS, shows the system in its entirety. Data is easily retrieved from the PCMCIA card using associated software (GR660Explore). Data can be binned according to a region of interest (ROI) for a predetermined radionuclide of interest or data can be retrieved for each of the 512 channels (gamma energy from 0 to 3 MeV). The GR660Explore software is capable of removing Compton continuum from the peaks provided the operator sets up the Compton ROI properly. Data can be imported into an Excel spreadsheet to facilitate mapping using industry standard software (i.e. ArcView and Surfer).

The system is capable of being operated with a computer to allow the operator to view the data real time to include visual observation of the GPS breadcrumb trail, via RS-232 telemetry to allow a remote user to observe the same data as the on board operator, or standalone without the use of a computer—the system stores the information on a PCMCIA card. The GR-460 console contains the multichannel analyzers (MCA) for each detector along with basic operation controls. The predominant controls are the automatic energy calibration using a Cs-137 source, gain stabilization using naturally occurring Th-232 progeny Tl-208 at 2.615 MeV, and recording the GPS coordinates with values associated with each detector channel each second on a PCMCIA card inside the console. The liquid crystal display (LCD) can indicate the data number, dose rate, or the GPS coordinates.

Operation is typically based on a predetermined survey plan with the accumulated data being stored on the PCMCIA card. Minimal evaluation of data is performed during the survey; however, the system is capable of displaying this information to the operator using a laptop computer. Post interpretation of actual "hard" data points allow all parties involved with the survey process to agree on information. Data evaluation is performed after each survey unit is complete.

Figure 1.Contamination Monitoring System (CMS)

QUALITY ASSURANCE

The system shall be calibrated prior to use with the automated energy calibration function built into the GR-460 firmware/hardware – placing the 662 keV gamma peak from Cs-137 at channel 115. Verification of instrument response shall be performed during each run with a Cs-137 check source – prior to start and at the completion (operator to evaluate data when the run is complete). Any source trends outside $\pm 2\sigma$ should be investigated and any values outside $\pm 3\sigma$ shall be investigated.

OPERATION

The system operation is extremely user friendly. The operator simply connects the cables (Detector 1, Detector 2, GPS, and User if computer connected), applies 12 VDC power, turns the console on (turn key to 1 position), performs energy calibration using Cs-137 source, and collects data.

The typical scan speed is 1 meter per second. Use of faster scan speeds require specific calculations of new minimum detectable activities; scanning faster than allowed may invalidate all data collected at elevated scan speeds.

Upon completion of the survey, the system is turned off and the PCMCIA card is removed from the console. The data is retrieved according to predetermined regions of interest (ROI) or spectral data file with associated GPS coordinates.

Data generated from the ROIs will be binned according to the following parameters background + 2σ, greater than 2σ but less than 3σ, and equal to and greater than 3σ. Staff should investigate values above 3σ using portable or in situ equipment to validate elevated readings. During certain evolutions, this arrangement might need to be modified due to large variations in naturally occurring background uranium, thorium, and radium; values as high as 6σ might need to be used.

The GPS will not work indoors.

GAMMA ENERGY CORRELATION

The system energy calibration was performed using its ability to capture spectral data files. The known gamma energies were then compared to the peak channel. A second order equation was calculated to convert from a channel number to its keV equivalent. Actual response and associated errors are referenced in Table 1, Energy Calibration.

Table 1. Energy Calibration

Radionuclide	Energy (keV)	Channel #	Error
Am-241	59.5	13	-0.35 keV
Th-234	92.4	19	1.96 keV
Cs-137	661.6	115	0.26 keV
Co-60	1173.2	200	-1.08 keV
Co-60	1332.5	226	-2.87 keV
Eu-152	1408	239	0.64 keV
Th-208 (Th-232)	2614.7	435	5.61 keV

Equation:
$\text{keV} = -16.88 + 5.845X + 0.0005X^2$
where X is channel number

EFFICIENCY CALCULATIONS

Measurements were made with discrete gamma sources that are traceable to the National Institute of Standards and Technology. Radionuclide standards were selected based on their highest energy gamma to reduce the interference from Compton scattering with the single exception of the 121.8 keV peak from Eu-152. Obtaining the 121.8 keV information was performed by retrieving 30 one-second spectral data files, conversion to an Excel file, and then to a text file with a TKA extension to allow the file to be imported into Canberra Genie 2k program. Compton removal was performed by the Genie 2k program.

The source was placed under the detectors and moved in increments of 10 centimeters until a field of 1 square meter was measured. The cps values were modeled to show the detector response patterns while the average net cps values were used for efficiency calculations.

Microshield modeling was performed for each source to calculate the fluence at the center of the NaI detectors and bottom of the detector cases. The average net cps values were then compared to the calculated fluence (gammas per 1 cm^2 per second) for the standard being measured. A net cps per 1 gamma per cm^2 per second was calculated for each of the gamma energies used to calculate the detector efficiency. A detection limit is then easily calculated by inputting radionuclide information into Microshield to determine the fluence of the specific gamma energies (ROI specific) at 25.6 cm (height of the detector above the surface). See Appendix A as an example.

Specific sources and gamma energies are referenced in Table 2, Calibration Data.

Table 2. Calibration Data

Radionuclide	Serial #	Gamma Energy keV	Activity (µCi)	Calculated Fluence gammas/cm^2/sec	Detector Response Net CPS	Efficiency – net cps per 1 gamma/ cm^2/sec
Am-241	MU-849	59.54	1.06	0.62	274	442
Eu-152	MU-853	121.8	1.08	0.50	220	440
Ba-133	MU-850	308/356/383	0.96	1.34	673	502
Cs-137	MU-851	661.6	1.07	1.47	477	327
Co-60	MU-852	1332.5	0.9	1.45	315	217

FLUENCE VALIDATION VS MATRIS

Surface data was obtained empirically using discrete sources every 10 centimeters. The average net cps was then compared to a single fluence value at the center of the detectors. Use of the single reference point as a soil matrix measurement was validated by calculating fluence measurements on the side and corner of the detector and comparing ratios (center fluence / side or corner fluence) to the single data point in the center. Only Am-241 and Co-60 were used to validate these measurements since they are at opposite ends of the gamma energies measured. Specific model parameters for the surface measurements includes a surface area of 1 square meter, source depth of 0.1 cm, density of 1.22 E-3 g/cc, and the current source activity. The matrix (soil) model parameters include a surface area of 1 square meter, source depth of 15 cm, a density of 1.6 g/cc, and the current source activity. The maximum ratio variation was between the Am-241 surface and matrix values which was 4.8%. Source dimensions deeper or larger will require validation. Ratios comparisons between Am-241 and Co-60 surface/matrix fluence are referenced in Table 3, Am-241 Fluence Comparisons and Table 4, Co-60 Fluence Comparisons.

Table 3. Am-241 Fluence Comparisons

Radionuclide	Surface – Center Fluence	Surface – Side Fluence (center/side ratio)	Surface – Corner Fluence (center/corner ratio)
Am-241-Surface	0.62	0.569 (1.09)	0.539 (1.15)
Am-241 - Soil	0.129	0.117 (1.1)	0.107 (1.21)
Variation (ratios)		-1.1%	-4.8%

Table 4. Co-60 Fluence Comparisons

Radionuclide	Matrix – Center Fluence	Matrix – Side Fluence (center/side ratio)	Matrix – Corner Fluence (center/corner ratio)
Co-60 - Surface	1.54	1.41 (1.09)	1.33 (1.16)
Co-60 - Soil	0.895	0.813 (1.1)	1.17 (2.39)
Variation (ratios)		-0.8%	-1.2%

EFFICIENCY CALIBRATION INFORMATION

The layout of the detectors in relation to the source measurements is referenced in Figure 2, Detector Calibration Layout. Visual representations of the detectors response to each source is referenced in Figures 3 to 7 while the detector value in cps is referenced in Tables 5 through 9.

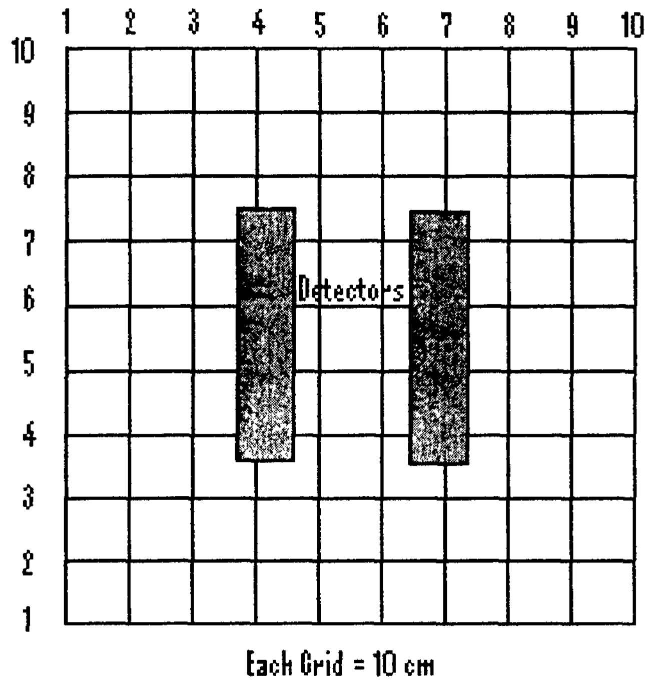


Figure 2. Detector Calibration Layout

Am-241
Average 274 Net CPS
1.06 uCi Point Source

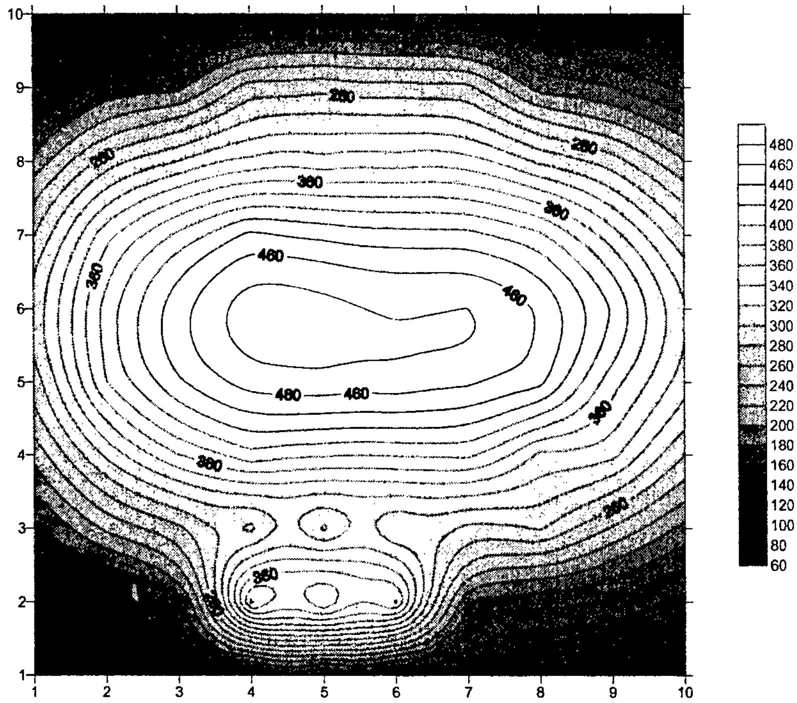


Figure 3. Am-241 Efficiency Map

Table 5. Am-241 Net CPS Calibration Data

	1	2	3	4	5	6	7	8	9	10
10	106	127	130	142	143	139	140	132	115	96
9	148	186	194	249	253	248	246	193	181	154
8	206	268	300	325	327	330	328	296	270	221
7	258	352	403	444	434	427	426	405	349	284
6	285	386	451	489	486	477	480	457	399	323
5	267	379	436	468	473	471	464	445	368	309
4	226	305	359	393	383	382	384	335	326	259
3	174	225	256	274	275	282	274	283	238	194
2	125	144	170	405	399	382	181	167	153	132
1	74	91	99	107	111	105	108	103	105	96

Ba-133
Average 673 Net CPS
0.96 uCi Point Source

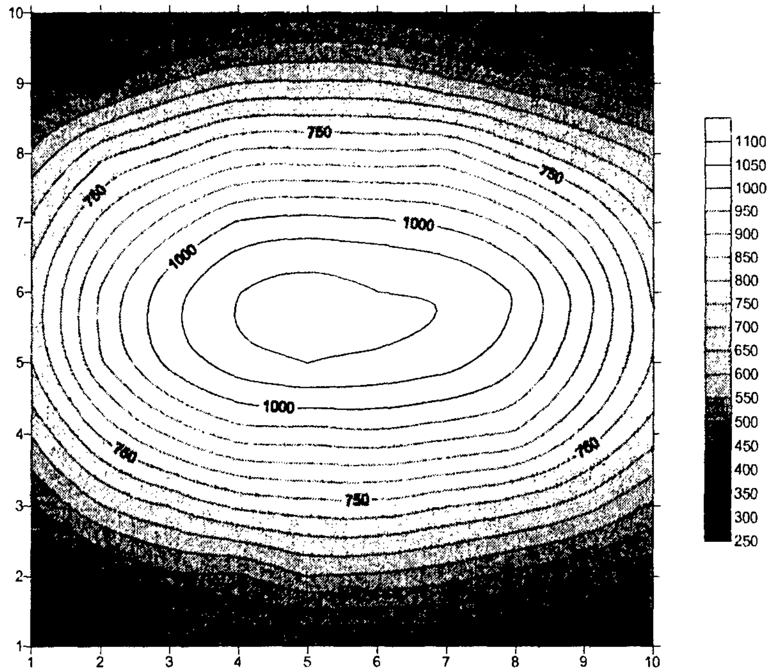


Figure 4. Ba-133 Efficiency Map

Table 6. Ba-133 Net CPS Calibration Data

	1	2	3	4	5	6	7	8	9	10
10	319	361	396	419	435	430	414	387	352	339
9	434	480	552	600	605	605	563	524	488	444
8	559	684	742	810	813	805	814	730	654	589
7	656	814	920	1005	1019	1010	987	930	822	687
6	716	907	1030	1099	1119	1100	1094	1045	921	741
5	698	895	1014	1076	1101	1088	1067	1009	890	745
4	602	757	858	926	927	939	916	893	785	670
3	493	597	652	711	729	732	702	673	623	541
2	373	437	490	526	549	542	519	481	448	407
1	271	300	328	364	345	341	353	335	318	301

Co-60
Avg 314.8 Net CPS
0.9 uCi

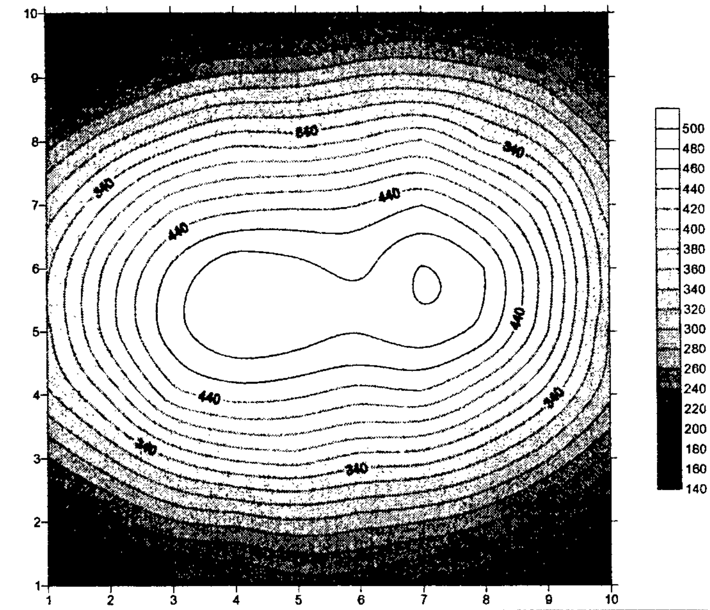


Figure 5. Co-60 Efficiency Map

Table 7. Co-60 Net CPS Calibration Data

	1	2	3	4	5	6	7	8	9	10
10	150	162	179	190	188	201	214	193	181	157
9	203	217	250	265	267	281	283	273	250	198
8	251	295	328	354	350	362	382	342	312	255
7	305	362	414	430	436	439	459	428	377	286
6	336	407	463	494	486	474	501	480	409	306
5	335	411	471	495	490	481	493	472	402	296
4	316	365	433	449	444	429	436	399	352	285
3	259	299	341	364	371	352	350	322	283	233
2	203	229	259	266	277	268	260	243	211	177
1	164	175	194	193	212	208	195	184	167	143

Cs-137
1.07 uCi Point Source
Average Value = 477 Net CPS

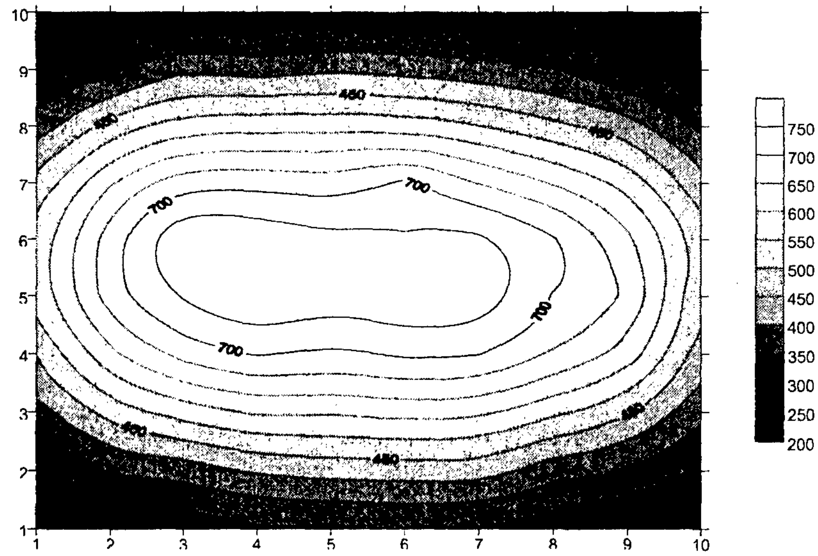


Figure 6. Cs-137 Efficiency Map

Table 8. Cs-137 Net CPS Calibration Data

	1	2	3	4	5	6	7	8	9	10
10	218	246	266	293	293	302	295	273	255	220
9	291	356	372	407	419	423	422	370	346	293
8	381	469	521	557	556	567	560	510	457	362
7	453	588	666	705	690	709	703	642	578	424
6	514	673	753	786	767	779	773	697	642	458
5	515	672	786	775	759	753	757	703	609	471
4	464	593	675	681	671	709	647	594	529	414
3	373	467	520	530	532	525	500	461	421	341
2	292	340	390	378	392	383	370	352	308	259
1	210	249	262	259	269	269	266	247	238	207

Eu-152
1.08 uCi Point Source
Average Value = 220 Net CPS

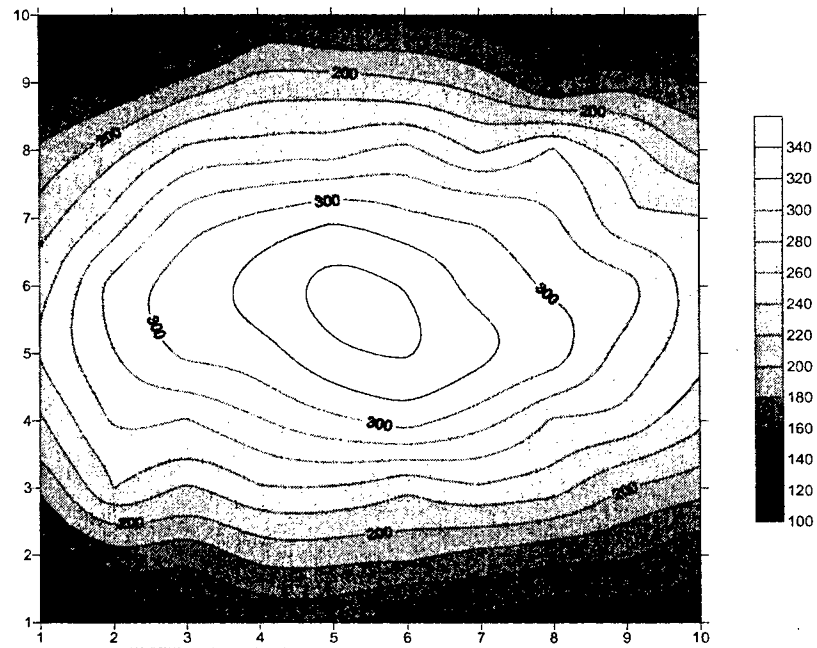


Figure 7. Eu-152 Efficiency Map

Table 9. Eu-152 Net CPS Calibration Data

	1	2	3	4	5	6	7	8	9	10
10	113	126	105	166	149	158	149	143	115	136
9	146	160	186	208	209	203	192	157	173	158
8	184	211	244	248	250	266	236	262	231	195
7	207	246	290	304	317	304	297	282	242	241
6	230	287	310	325	348	339	311	295	288	250
5	241	279	304	310	335	341	325	310	271	245
4	216	262	258	278	295	309	287	257	253	225
3	182	240	218	238	238	224	237	228	199	187
2	148	174	165	188	188	186	174	166	163	145
1	133	133	132	145	145	128	137	123	132	129

(This Page Intentionally Left Blank)

Appendix A

Depleted Uranium Modeling

(This Page Intentionally Left Blank)

Appendix A

DEPLETED URANIUM

To facilitate use of the equipment, predetermined ROIs have been calculated for various radionuclides. The actual gamma energies and channel numbers associated with each ROI are referenced in Table 1, Regions of Interest. Background counts and/or ratios will need to be performed for each background type in the area being surveyed, such as different soils, asphalt, concrete, etc.

The survey unit is mapped using DU-1, DU-2, and DU-3. DU-1 is optimized for locating residual DU contamination and discrete metal fragments. DU-3 is optimized for locating discrete metal fragments of DU.

$$\text{Net U-238 (Pa-234m)} = \text{ROI } 6 - (\text{ROI } 8 * \text{SR})$$

Table A-1. Regions of Interest

ROI	Description	Lower Channel	Upper Channel
3	DU-1	11 ch (47.5 keV)	188 ch (1100 keV)
6	DU-2	159 ch (925 keV)	188 ch (1100 keV)
7	DU-3 – Compton Removed	159 ch (925 keV)	188 ch (1100 keV)
8	DU-4 – Compton Background	189 ch (1105 keV)	509 ch (3088 keV)

- DU-1 Encompasses the vast majority of photons emanating from DU
- DU-2 Gross Pa-234m (U-238 progeny) counts
- DU-3 Pa-234m with Compton subtracted (Compton subtraction ratio (SR) to be calculated for each type of material being surveyed)
- DU-4 Pa-234m Compton

Detector Response for DU

Data referenced in this section is only for calculating a priori detection limits and should not routinely be used as a conversion tool for converting detector cps to a pCi/g value for DU. Contamination is rarely in the form of a homogenized mixture, but may be in the form of discrete particles, small localized contamination, or even a large irregularly contaminated area. Since the distribution of the contamination is not known prior to performing the survey or even immediately after the survey, data generated by the instrument should be used carefully.

DU contamination usually comes in two types: discrete metal fragments and oxidized DU in a soil matrix. Unfortunately, even the oxidized DU will tend to stay together and slowly migrate into the soil unless outside mechanical forces spread the oxide. For the purposes of this document, only oxidized DU in a soil matrix will be modeled. It is extremely difficult to calculate detection limits for discrete DU metal fragments since the emission of the photons (including Bremsstrahlung X-rays) is dependant on the surface area presented to the detector and depth if the source is buried.

Microshield was used to model the photons generated from a soil matrix 1 meter by 1 meter by 15 centimeters deep. For the model, assumptions included: 100 pCi/g DU, soil density 1.6 grams/cc, no Bremsstrahlung production, detectors are 25.6 cm above the surface, and a scan speed of 1 meter per second. Uranium contributions calculated for the model are as follows: U-234 - 15.2 pCi/g (< 0.01% by mass), U-235 - 1.1 pCi/g (0.20% by mass), and U-238 - 83.7 pCi/g (99.8% by mass). Values input into Microshield are U-235 = 1.76 pCi/cc and U-238 = 133.9 pCi/cc to compensate for conversion from pCi/g to pCi/cc with density of 1.6 g/cc. No values were input for U-234 because it is an alpha emitter only and its progeny has a long half-life.

Table A- 2. DU Fluence Per Energy

keV	**Fluence - Microshield**	**Efficiency**	**CPS**	**Gamma Eff. Used**
	(gamma/cm^2/sec)	cps per gamma/cm2/sec		
60	2.7 E-1	440	1.2 E2	122 keV
80	3.6 E-2	440	1.6 E1	122 keV
100	9.6 E-1	440	4.25 E2	122 keV
150	4.7 E-2	440	2.1 E1	122 keV
200	1.6 E-1	440	7.1 E1	122 keV
300	2.2 E-3	502	1.1	360 keV
400	1.9 E-3	502	9.5 E-1	360 keV
500	2.7 E-3	327	9.0 E-1	661.9 keV
600	1.1 E-2	327	3.6	661.9 keV
800	6.2 E-2	217	1.3 E1	1332 keV
1000	2.0 E-1	217	4.3 E1	1332 keV
Sum	1.76		7.1 E2 per 100 pCi/g DU	
			7.1 per 1 pCi/g DU	

For the purposes of calculating a typical detection limit, an average background value for DU-1 was 3300 cps with a standard deviation of 60 cps. Background ambient radiation levels were 6 μR/hr. This equates to the following detection limits:

Background + 2σ (84 ncps) = 12 pCi/g DU
Background + 3σ (126 ncps) = 18 pCi/g DU
Background + 6σ (253 ncps) = 36 pCi/g DU

DU-2 is centered around the 1001 keV Pa-234m peak. A detection limit was not calculated since the yield is so low, however, it is an excellent mechanism for validating the presence of DU when there is a large variation in background due to naturally occurring thorium and radium.